

DEPLOYMENT CHARACTERISTICS OF SEAT MOUNTED SIDE IMPACT AIRBAGS

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ABSTRACT

There are over 230 current model year vehicles in the U.S. market that offer seat mounted side airbag systems. Compared to the considerable amount of crush space present in frontal crashes, the relatively limited amount of crush space available in side crashes creates a challenge for side airbag deployment performance. In the case of seat mounted side airbag technology, when the side impact sensor senses an impact that warrants deployment, it sends a deploy signal to the airbag module located in the outboard seat bolster. The airbag must then deploy from the seat and continue to move into position between the occupant and the interior door surface before the gap closes due to the intruding object. The deployment timing and positioning of the airbag is critical in providing enhanced occupant protection.

In this study, 88 front seat mounted side airbag systems from 1999-2010 model year vehicles were analyzed. The side airbag systems included airbags that deploy through seat bolster seams and systems that deploy through discrete seat deployment doors. Of the 88 production seat side airbag systems tested, 38 were equipped with side airbags that provide only thoracic coverage, 27 provided a combination of head and thoracic coverage, and 23 provided thoracic and pelvic coverage. Seventy-eight of the systems were unique; ten of the systems were repeat deployments.

The front seats equipped with side airbag systems were mounted on a generic fixture with the outboard seat bolster packaging the airbag placed approximately 100 mm from a Plexiglas reaction surface. The Plexiglas was backed with a grid of 2 inch squares to utilize in film analysis of the deployment. High speed cameras were placed to capture front, profile, and rear views of the airbag deployment.

The deployment time intervals associated with initial break out (airbag first becomes visible), two inch

extension forward, six inch extension forward and full extension position were recorded. The average deployment time calculated for break out, two inch extension, 6 inch extension, and full extension deployment intervals for the total set of seats was calculated as 3.3 ms, 5.0 ms, 7.3 ms, and 14.9 ms, respectively. The standard deviation characterizing the variation within each deployment interval was calculated as 1.17, 1.17, 1.83, and 5.73 ms, respectively. Further comparisons of average time and variation in timing between types of side airbags (thorax, head/thorax, and pelvis/thorax), deployment mechanisms (through seam vs. discrete door), repeat deployments, and across model years were also made. Discussion regarding the factors that influence the variation in deployment timing among the airbag types, deployment mechanisms, and model year groupings is included.

INTRODUCTION

Side airbags entered the market in 1995 appearing on limited Mercedes Benz and Volvo models. Today there are over 230 current model year (2011) vehicles that offer seat mounted side airbags systems. This is approximately 85% of the new passenger vehicle models available in the U.S. market place. With recent change to Federal Motor Vehicle Safety Standard, FMVSS 214, side airbags will eventually become standard equipment on most passenger vehicles by 2014[1].

Passenger vehicles provide side impact protection through vehicle structural design and energy absorbing materials. Seat mounted side impact airbags are an energy absorbing component of a system providing occupant injury control. The side airbag not only interfaces with the seat where it is packaged but also with the side interior door and pillar trim.

The distance between the point of contact on the side of a vehicle and the occupant seated in the front seat in a typical side impact is limited to a few inches.

This small distance places great demands on side airbag performance for sensing deployment decision, breakout, and inflation to full capacity.

Seat mounted side airbags are packaged relatively close to the occupant. They are concealed within the outer bolster of the seat back. The modules are built into the seat and deploy through a seam in the seat trim or through a separate cover often referred to as an exposed deployment door (Figure 1). To achieve desired performance from the side airbag, the deployment timing to break out of the seat and continue to move into position between the occupant and intruding surface requires optimization. The side airbag module generally consists of an inflator, air bag or “cushion,” and cover. The module inflates when it receives a signal from the sensor, commanding deployment in certain types of side impact accidents. There are three basic types of side airbags, those that provide thoracic coverage, combination head/thoracic coverage, and combination pelvic/thoracic coverage.



(a) Built in seat – deploys through seat seam

(b) Separate module – deploys through a deployment door

Figure 1. Seam deployment vs. deployment door.

Prior to the FMVSS 214 requirement that was released in September 2007 (with phase in beginning in 2010) side airbag systems were not necessary to satisfy regulatory requirements for side impact occupant protection. Manufacturers developed their vehicles to their internal requirements guided by government regulated side impact full vehicle crash tests.

In 2000, a voluntary agreement was released to guide the performance of side airbags systems when evaluated to occupant out of position testing. Vehicle systems developed after the 2000 calendar year were designed to comply with the Technical Working Group’s Recommended Procedures for Evaluating Occupant Injury Risk from Deploying Side Airbags (referred to as the TWG procedures) [2].

In 2003, the Insurance Institute for Highway Safety (IIHS) released a new consumers rating tool, the IIHS Moveable Deformable Barrier Side Impact test (referred to as IIHS MDB) [3]. The IIHS procedure applied new requirements on side impact performance which influenced side airbag design and performance. Due to changes in the public domain, working group and regulatory requirements over time, side airbag designs have also evolved and changed. As side airbags systems evolved to meet the new requirements, the rate at which they deploy from the seat, the size, shape and volume of the airbags, and the internal pressure characteristics of each airbag changed over time.

VEHICLE SYSTEMS ANALYZED

A vehicle set consisting of vehicles equipped with seat mounted side airbags was identified. The set was composed of the following vehicle brands: Acura, Audi, Buick, Cadillac, Chevrolet, Chrysler, Dodge, Ford, Honda, Hyundai, Infiniti, Jaguar, Kia, Lexus, Lincoln, Mazda, Mercedes-Benz, Mercury, Mini, Mitsubishi, Nissan, Pontiac, Saab, Saturn, Scion, Subaru, Suzuki, Toyota, Volvo, and Volkswagen. Vehicle models in model years 1999-2010 for which seat mounted side airbags were available as either standard or optional equipment were identified. Determinations of availability of seat mounted side airbags were made by consulting the IIHS online “Vehicles Equipped with Side Airbags” database as well as other automotive websites and resources (4, 5, 6).

TEST PROTOCOL

Static ambient side airbag deployment testing was used for the purposes of evaluating the side airbags deployment.

Autoliv America’s Auburn Hills Technical Center, an accredited test facility in airbag deployment with extensive experience in seat mounted side airbag deployments, was chosen as the test facility.

For each test, the production seat system was mounted to a test platform through the seat track attachment points. Vehicle specific seat attitude as positioned in its unique vehicle environment was unavailable therefore a simulated position was used. Mounting blocks were constructed to allow for level attachment of the seat to the test platform. The seat track angle was adjusted to $0^\circ \pm 3^\circ$ from horizontal. When the inclinometer was placed on the seat cushion in the middle of the seat it read approximately $15^\circ \pm 5^\circ$ for the majority of the

samples. The seat was placed in the full rear seat track position. Seats that adjusted up/down were placed in the full down position. The seat back angle was measured on the back outboard side of the seatback and was adjusted to $20^\circ \pm 2^\circ$ which correlated to a $5^\circ \pm 2^\circ$ measurement at the headrest posts on most samples.

Each seat was orientated such that the outboard bolster containing the side airbags was positioned next to a Plexiglas reaction surface. The distance between the side bolster and the Plexiglas surface was approximately 100 mm at the airbag location.

The Plexiglas was backed with a grid of 2 inch squares to utilize in film analysis of the deployment.

For deployment a DC current of 3.5 A +/- 0.5 A was applied to the side airbag module through squib wires for 3 ms. The module electrical resistance (terminal-to-terminal) was verified pre-test. The fire command current was measured and recorded for each test.

Three camera views were used to capture the deployment (Figure 2). The film speed was 2000 fps, which allowed capture of 0.5 ms intervals during deployment. Photographs were taken before and after deployment.

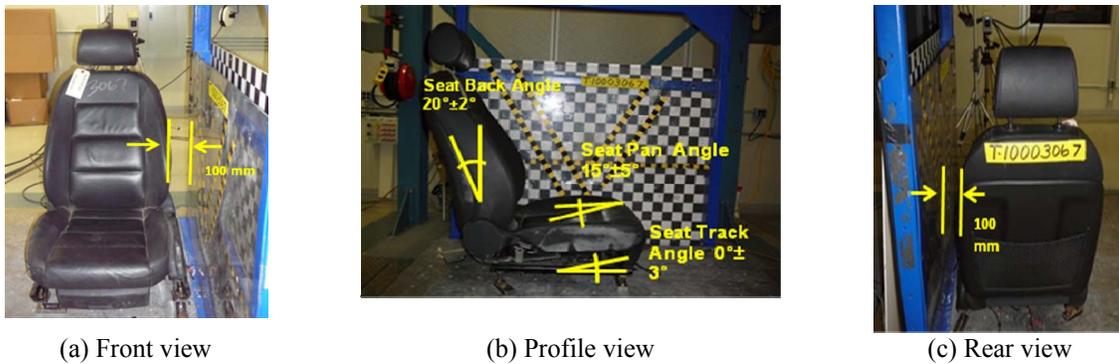


Figure 2. Test set up.

DEPLOYMENT ANALYSIS

There were four stages of deployment at which deployment timing comparisons were made: initial break out, two inches extension forward of the seat bolster, six inches of extension forward of the seat bolster, and full extension.

Initial break out was the first instant the seam splits or deployment door opens and bag material can be seen. The second measurement point was defined as the instant at which the bag reaches two inches forward extension. The third measurement point was defined as the instant at which the bag reached six inches forward extension. The final measurement point was defined as full extension of the bag. Full extension requires some amount of judgment and was determined by viewing the deployment frame by frame until it appeared maximum shape was maintained, i.e. if advancing to the next frame the bag appeared to be deflating or reducing in size the previous frame captured the full shape.

Using a frame by frame software viewer, deployment of the airbag was analyzed. The front view was used to determine the initial time at which the bag was visible through the seat seam or deployment door. The profile view was used to track the extension of the bag two and six inches forward of the seat bolster referencing the distance off the checkered grid and the time was noted. Full extension timing was determined using all three views. It was defined as the time the bag appeared to be completely extended forward, up, and down and advancing one more frame the bag appeared to be reducing in size.

When analyzing repeat deployment timing for a single design, the deployment views from each test were viewed side by side to compare the deployment shapes at the various intervals. The extension times recorded reflected the instant at which the two samples appeared to have had the same shape for each extension interval.

Since side airbag system deployment varies for each vehicle sample, it is difficult to set a standard location on each seat to measure the extension. As a

guideline, the point at which the seat bolster first expanded forward was used (Figure 3).

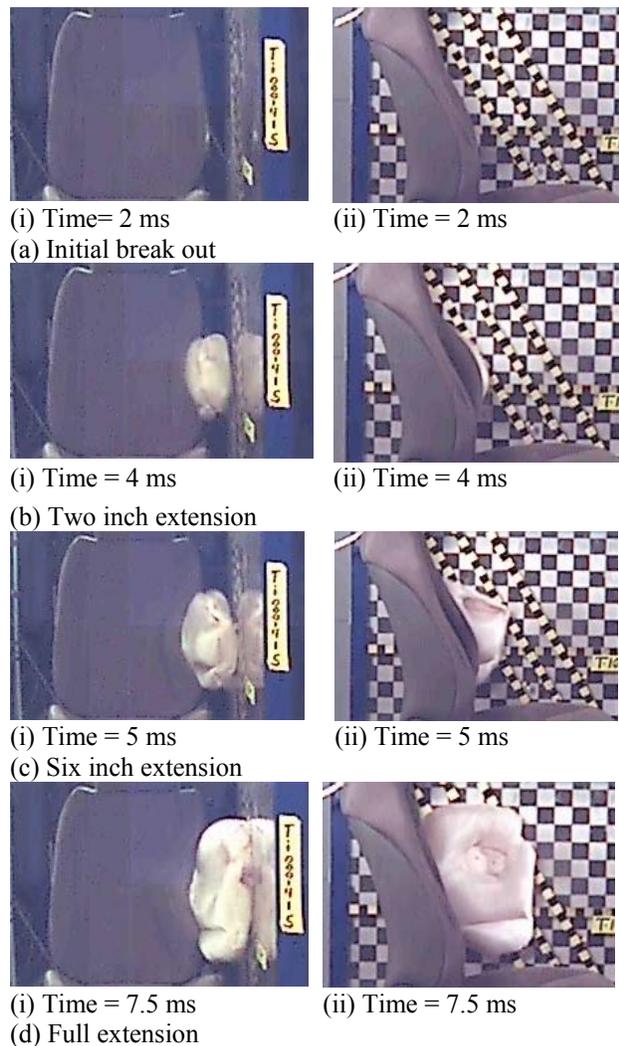


Figure 3. Example of deployment analysis.

DEPLOYMENT TIMING RESULTS

Total Samples

There were 88 vehicle seat side airbag systems evaluated: 38 thorax bags, 27 head/thorax bags, and 23 pelvis/thorax bags. Out of the 38 thorax bag systems, one system was only evaluated for break out time due to error in setup. The average break out time for the total set was 3.3 ms. The average extension times were 5.0 ms, 7.3 ms, and 14.9 ms for two inch, 6 inch, and full extension, respectively.

The corresponding standard deviations were 1.2, 1.2, 1.8, and 5.7 ms respectively. Part of the variation in average deployment timing across the total set can be contributed to the three types of side airbags. Thorax bags are smaller in size and volume than head/thorax and pelvis/thorax bags. Head/thorax bags generally are larger than both thorax and pelvis/thorax airbags. The volume of the airbag increases as the airbags unfold during extension and positioning. Breakout and two inch extension exhibit the least amount of variation presumably because the size and volume of the bag at those increments has less influence during initial deployment.

Comparing breakout times for side airbag type, the average breakout times were 2.83 ms, 3.48 ms, and 3.93 ms for thorax, head/thorax and pelvis/thorax, respectively. Referring to Figure 4, the mean breakout times were plotted along with their 95% confidence intervals (CI). The analysis does not reveal a significant difference between head/thorax and pelvis/thorax average breakout times, but thorax bags appear to breakout and become visible quicker on average than pelvis/thorax and head/thorax bags. However, this is not true in general for individual comparisons; there are some cases for which thorax breakout times exceeded the majority of pelvis/thorax and head/thorax times. The samples of thorax bags included significantly more deployment door systems than head/thorax and pelvis/thorax bags.

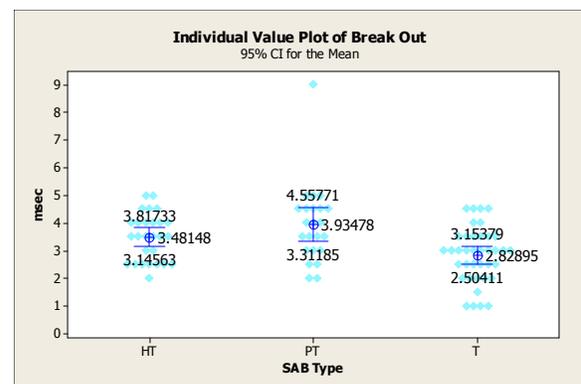


Figure 4. Breakout times for head/thorax (HT), pelvis/thorax (PT), and thorax (T) air bags.

Deployment Mechanism

This section analyzes the deployment timing of the side airbags broken down into deployment mechanism types: deployment doors (C), and seam deploy (S). The average breakout times were calculated to be 2.25 ms and 3.67 ms for deployment doors and seam deploy, respectively. The 95% confidence interval suggests average breakout times are significantly different (Figure 5).

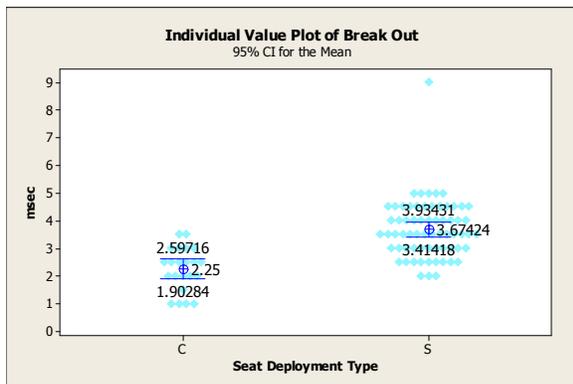


Figure 5. Breakout times by deployment type: door (C) and seam deploy (S).

As the bags extend forward, the average two inch extension times were calculated to be 4.83 ms for deployment door types and 5.08 ms for seam deploy. The 95% confidence intervals for the two deployment types overlap each other completely, so there is no indication that average two inch extension times for the two types were significantly different (Figure 6). Although the breakout times (defined as when the bag is visible) were different on average, at the time of two inch extension deployment characteristics for seam deployed side airbags and door deployed side airbags are extremely similar on average with the 95% confidence interval for seam deploy falling within the confidence level for deployment doors. This suggests that the motion of the bag forward is not, in general, influenced by the deployment mechanism type: deployment door vs. seam deploy. The average extension times at 6 inches and full extension were 6.64 and 12.26 ms, respectively, for deployment door modules and 7.51 and 15.74 ms for seam deploy modules. As bags begin to extend forward, their size and volume begin to influence the rate at which they deploy. A side airbag system that

may have very similar bag size and volume can vary in fold pattern resulting in extension time differences. The fold may be unique to balance in position timing performance with other requirements such as occupant out of position performance (Technical Working Group's Recommended Procedure for Developing Side Airbags) [2]. Slower extension does not mean an airbag system is inadequate. The performance of the complete system needs to be considered as other features of the system may compensate for extension timing. The study discussed in this paper did not analyze complete vehicle systems which would include but not be limited to vehicle specific door trim panels, intrusion rates and occupant position.

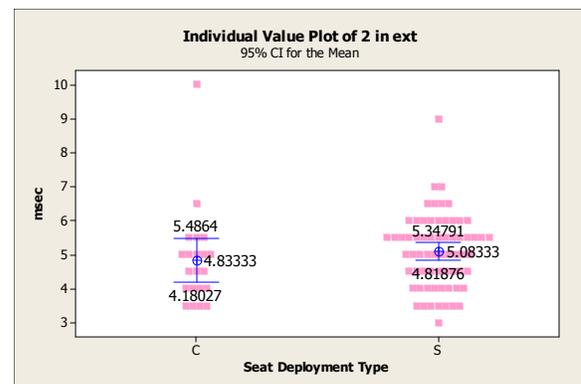


Figure 6. Two inch extension times by deployment type: door (C) and seam (S).

Thorax Systems

There were a total of 38 thorax bag samples: 22 seam deploy and 16 deployment door designs. All 38 were used in analyzing breakout time. Only 37 of the 38 were used in extension time analysis due to error in sample set up which reduced the door deploy samples to 15.

The average breakout time for thorax bags was 2.22 ms for deployment door modules and 3.27 msec for seam deploy modules. Calculating and plotting the confidence intervals indicates that the breakout times are different (Figure 7).

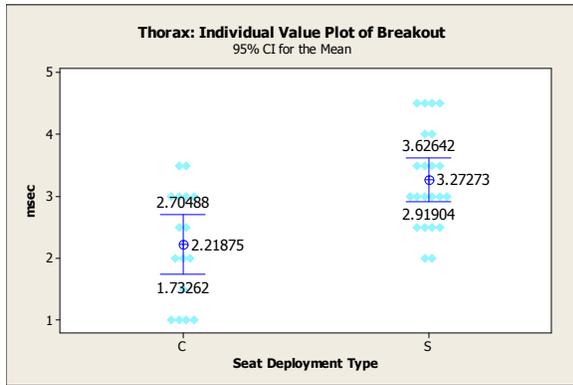


Figure 7. Thorax module breakout times by deployment type: door (C) and seam (S).

The average deployment time for two and six inch extension and full extension were 4.97, 6.87 and 10.83 ms, respectively, for deployment door module systems and 3.27, 4.80, and 11.5 ms for seam deploy module systems. The 95% confidence intervals were largely overlapping for the three extension times, so there was no indication that average extension times were significantly different (Table 1).

Table 1. Thorax extension time comparison

Extension (ms)	2 inch		6 inch		Full	
	C	S	C	S	C	S
Upper 95% CI	5.89	5.32	7.97	7.76	12.35	12.81
Average	4.97	4.80	6.87	7.07	10.83	11.50
Lower 95% CI	4.04	4.27	5.76	6.38	9.31	10.19

Ten of the thorax deployment door module systems were from seats taken from different models within sister brands.

Head/Thorax Systems

Twenty-seven head/thorax systems, including 22 seam deploy modules and five deployment door modules, were included in the analysis. All five samples of deployment door modules were from different models within sister brands. The average breakout for deployment door modules was 2.40 ms and 3.73 ms for seam deploy modules. Calculation of the 95% confidence intervals suggested a significant difference in average breakout times (Figure 8).

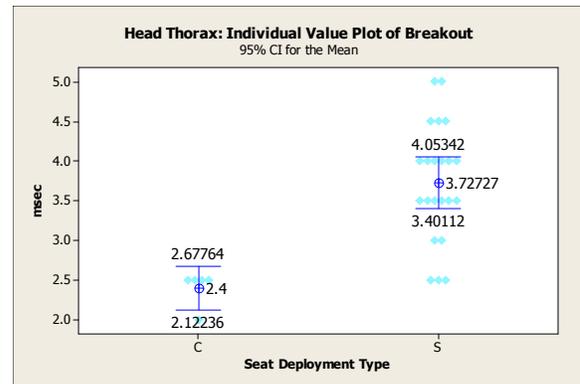


Figure 8. Head/thorax module breakout times by deployment type: door (C) and seam (S).

The two inch extension averages were very similar for deployment door systems and seam deploy systems at 4.60 ms and 4.91 ms, respectively. The upper and lower 95% CI were also calculated (Figure 9). The data does not indicate a significant difference in extension timing.

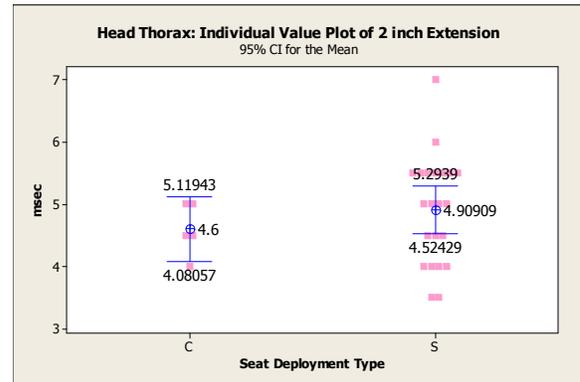


Figure 9. Head/thorax module two inch extension times by deployment type: door (C) and seam (S).

The six inch extension time averages were 6.30 ms and 7.09 ms for deployment door systems and seam deploy systems, respectively. Some overlap in 95% confidence intervals indicated that average extension times may not be significantly different, but timing appears more variable for seam deploy systems (Figure 10).

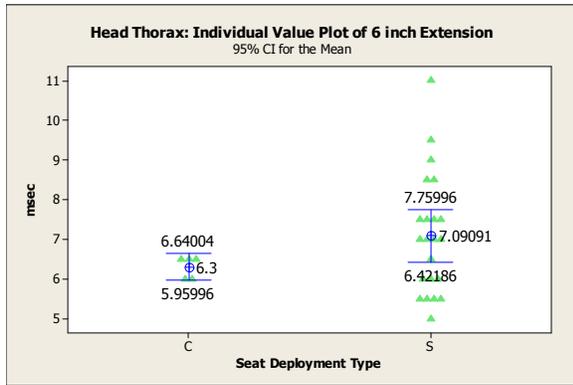


Figure 10. Head/thorax module 6 inch extension times by deployment type: door (C) and seam (S).

The average times for full extension in deployment door systems and seam deploy systems were 17.5 ms and 20.32 ms, respectively. The seam deploy system's 95% CI fell within the deployment door system's 95% CI (Figure 11).

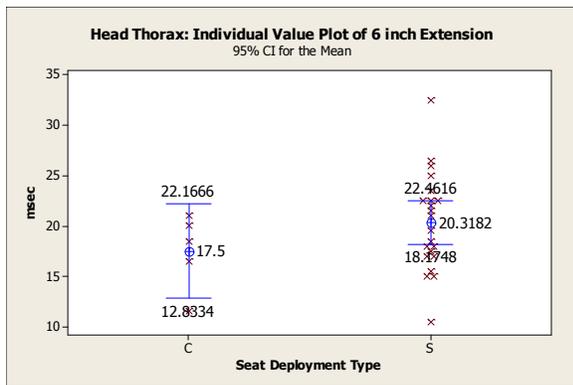


Figure 11. Head/thorax module full extension times by deployment type: door (C) and seam (S).

Although these results indicate that deployment mechanism may not influence extension times, the timing comparison is influenced by the limited sample size for deployment door systems. The deployment door systems are all from different models within sister brands with very similar bag sizes and shapes. The seam deploy systems are from a variety of U.S. and foreign manufacturers.

Pelvis/Thorax Systems

There were 23 pelvis/thorax system samples. Twenty-two were seam deploy modules and one was a deployment door module. Due to the lack of

deployment door modules, the analysis between the deployment mechanisms could not be conducted.

Bag Type Affects on Seam Deploy Modules

All three bag types had 22 samples each for deployment through the seat seam. Although the data did not indicate a significant difference between head/thorax and pelvis/thorax seam deploy breakout, thorax bags did appear to break out quicker. Average extension times at two and six inches for head/thorax and thorax systems did not appear to be significantly different, but the pelvis/thorax systems appeared to take longer to breakout and position on average. At full extension there is a significant difference between thorax, head/thorax and pelvis/thorax airbags (Figure 12). Size and volume of the airbags influence the full extension timing.

The pelvis/thorax airbags exhibited longer breakout, two inch, and six inch extension times on average. Pelvis/thorax bags are located lower in the seat back extending from above the arm rest to below the armrest to cover the occupant's torso and pelvis. The majority of thorax and head/thorax airbags are packaged at or above the armrest providing coverage to the occupant's torso in the case of thorax bags and torso and head in the case of head/thorax bags. Since the package of the pelvis/thorax bag is lower there is opportunity for interaction with child occupant out of position placement "child lying on seat" and "child lying on arm rest" as defined in the Technical Working Group "Recommended Procedures for Evaluating Occupant Injury Risk from Deploying Side Airbags [2]." The majority of thorax and head/thorax side airbags deploy above the child placement. The deployment onset of the airbag may be reduced to minimize the force applied to the child dummy. The onset of airbag deployment must be balanced to meet in position timing and to avoid causing inflation induced injuries.

Longer breakout and two and six inch extension times for pelvis/thorax bags are also likely influenced by the package length of this type of airbag. The majority of thorax and head/thorax bags are packaged such that there is a larger force (mass of the bag pack coupled with the inflator onset) concentrated on a smaller seat seam area. The pelvis/thorax bag package tends to extend along a greater seat seam length to assist in positioning above and below the armrest. This characteristic reduces the force

concentration (less bag pack) on the seat seam compared to head/thorax and thorax airbags.

Repeat Deployments

There were 10 pairs of samples for which repeat deployment data was available (i.e. the same airbag was deployed twice). There were four sets of pelvis/thorax airbag samples and 3 sets of head/thorax and thorax airbag samples.

The average differences in breakout, two, six, and full extension were 0.40, 0.60, 1.15 and 1.76 ms, respectively. All pairs had some difference in timing throughout their deployment, with the greatest differences being exhibited at six inch and full extension. Thorax airbags had the least amount of variation in difference and pelvis/thorax had the most amount of variation in differences (Figure 13).

Deployment Time Trends over Model Years

Deployment timing across model years appeared to be consistent (Figure 14). Some variation from year to year was present, but this variability was likely at least in part due to the limited number of samples of each type of side airbag for each model year. The plots highlight the trend of pelvis/thorax bags having greater breakout and two and six inch extension times. Full extension differences were most likely due to bag size differences.

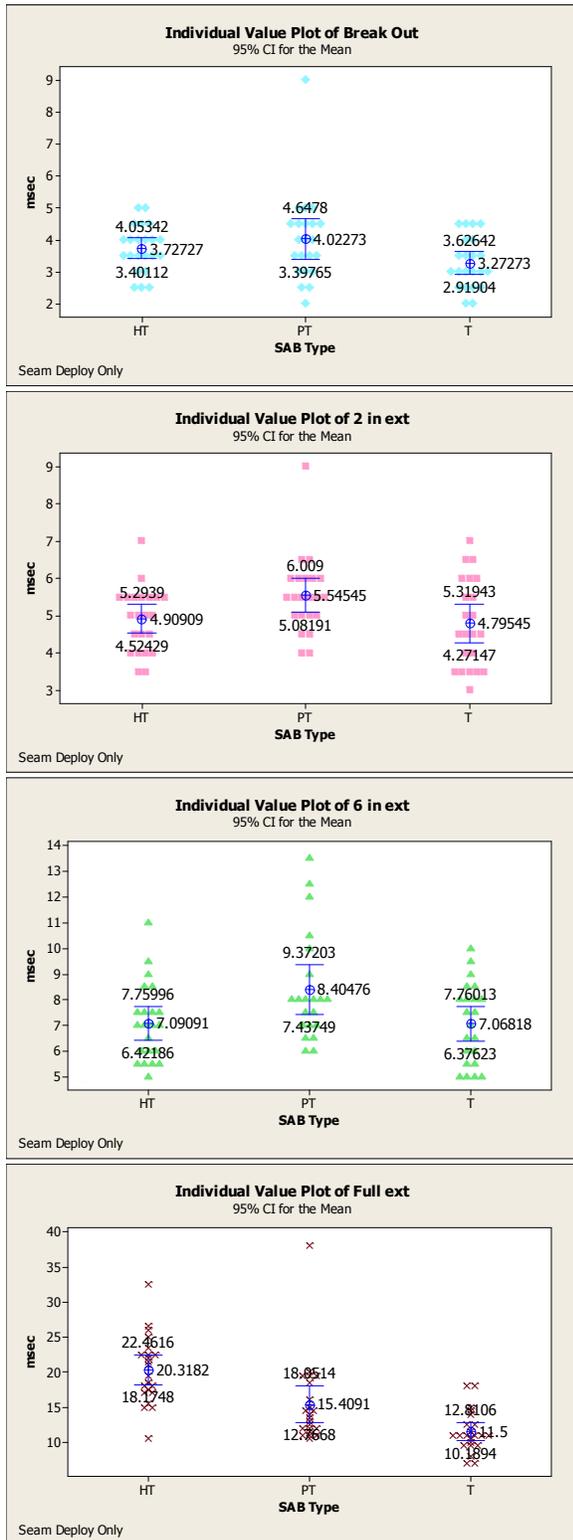


Figure 12. Seam deploy extension timing.

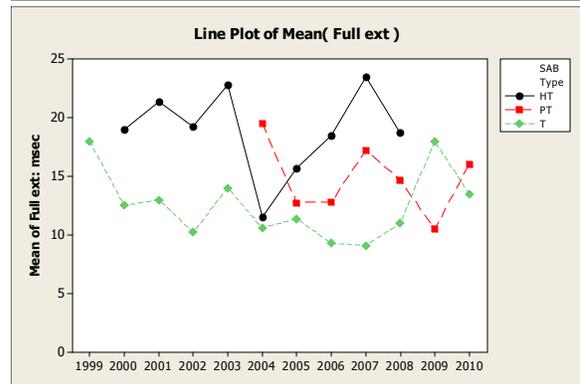
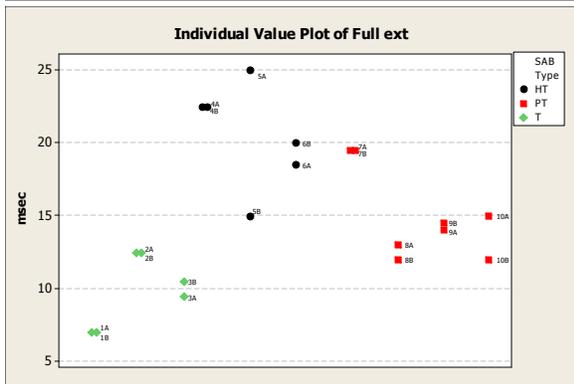
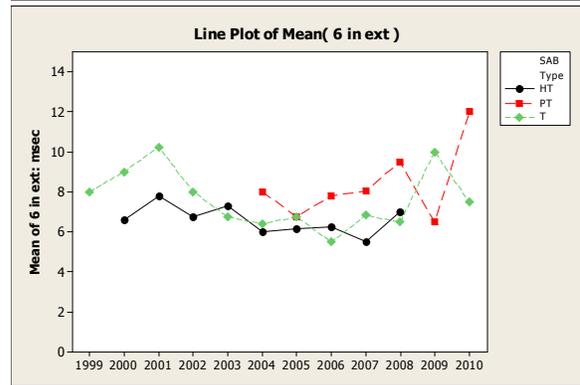
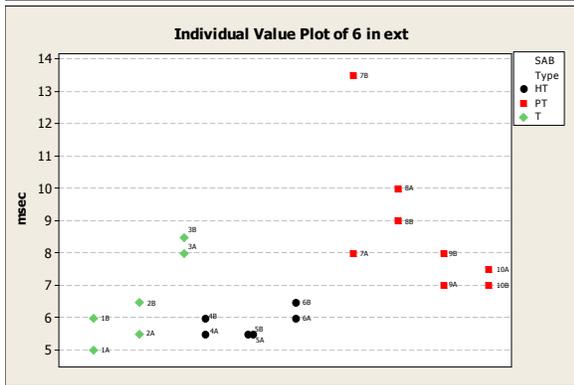
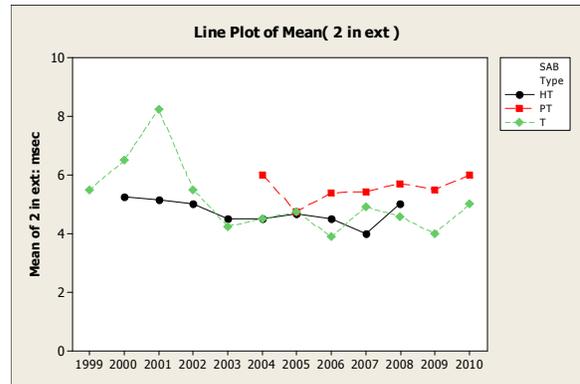
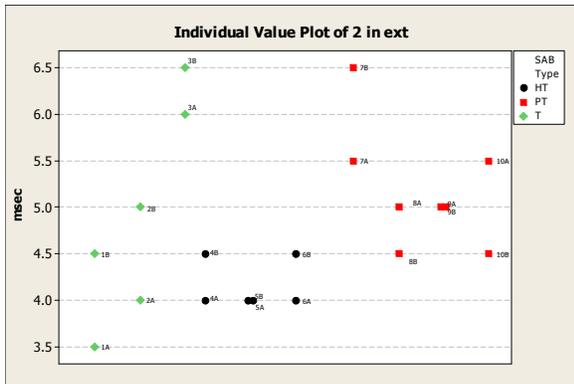
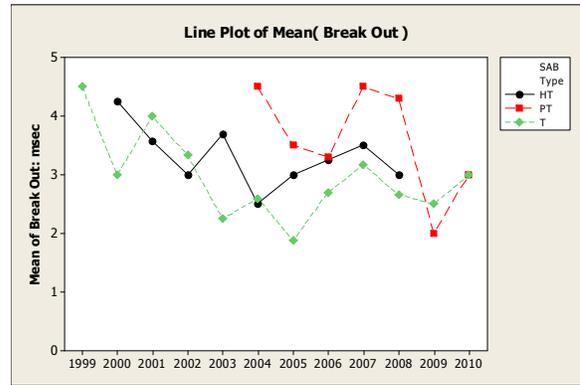
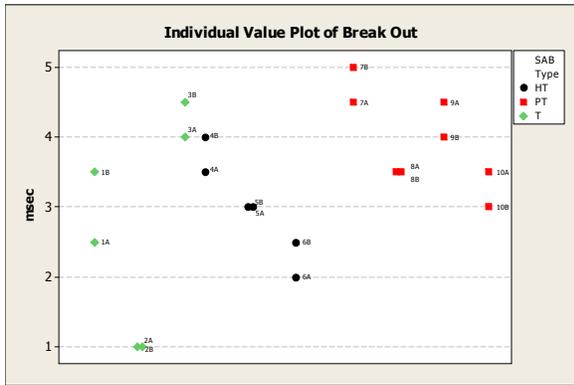


Figure 13. Repeat deployment variation.

Figure 14. Deployment timing across model years.

CONCLUSIONS

Breakout time of pelvis/thorax and head/thorax side airbags was similar whereas thorax bags were slightly faster. Further analysis suggested deployment door modules appeared quicker than seam deploy but deployment door systems and seam deploy systems extended forward to positions at similar rates within bag types.

Regardless of the deployment mechanism, deployment door or seam deploy, the extension times to position were similar for thorax systems. Within each bag type, thorax systems had the least variability. This can be attributed to the bag size and volume being smaller relative to head/thorax and pelvis/thorax bags and bag shapes having greater similarity across brands.

Head/thorax systems appeared to have more variability at the six inch and full extension times. This can be attributed to larger bag size, volume and shape variability.

Pelvis/thorax bags trended longer for average breakout and two and six inch extension timing compared to thorax and head/thorax systems. The longer breakout time is attributed to the characteristics inherent in the design to meet vehicle level requirements.

The repeat deployments indicated there is inherent variability within the same module type. The greatest differences were apparent at six inch and full extension.

Average deployment times of airbag types across model years appeared to be relatively consistent.

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